AMERICAN JOURNAL OF ALTERNATIVE AGRICULTURE, Vol. II(2):69-73. 1987.

Legumes: Their potential role in agricultural production

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Abstract. *The energy crisis of the late 1970's has raised the question of the wisdom of depending upon fertilizer nitrogen as the primary source of N input into crop production systems. While present and past price structures have favored fertilizer-N over biologically fixed N, there are a number of other benefits of legumes in a cropping system in addition to their effects on N availability. Among these are less potential for environmental degradation and improved soil physical conditions and water relations, but it is difficult to assign economic value to many such benefits. In addition to the economics of the present price structure, disadvantages of using legumes could include reduced total production and increased need for livestock in a farming enterprise (these could be considered assets from some aspects). Legumes are presently used in short-term rotation, such as corn-soybean, or in continuous corn with a legume winter cover crop. These systems are finding widespread use and offer the producer many benefits, as well as helping to solve several major environmental problems associated with N use in agriculture.*

Introduction

Legumes have been used in agricultural production since the earliest of civilizations. They have served as the primary source of nitrogen for many cropping systems, as well as providing food for humans and domestic animals. In many developing agricultural regions of the world, legumes are still used extensively for these purposes.

In the last several decades, the widespread availability of synthetic nitrogen fertilizer in many nations has resulted in a major decrease in the cultivation of legumes (Figure 1). An exception to this trend has occurred for soybean *(Glycine max)*, a widely grown grain legume that has increased within the last five decades in the United States from almost nothing to tens of millions of hectares. Although soybean grown in rotation with corn *(Zea mays)* enhances corn production (Voss and Shrader, 1984; Hesterman et al., 1986), studies with N-isotopes indicate that after harvest of the soybean seed, soybeans contribute little if anything to total soil N (Heichel, 1987).

The exclusion of other legumes from cropping systems these last several decades resulted not only from the availability of fertilizer N, but was also accelerated by the conversion to fossil energy as a source of power for American agriculture. Because of this change, farmers were no longer compelled to use as much as 25 percent of their land for the production of forage and grain for draft animals. Many farmers eliminated all livestock from their operations, moving to cash grain enterprises and making them entirely dependent upon nitrogen fertilizers as their source of added N.

The energy crisis of the 1970's, with attendant increases in cost and reduced availability of N fertilizers, caused many producers to evaluate the stability of continued dependence on synthetic N fertilizers as their only N input. Even though the initial energy crisis has abated somewhat in recent years, economic stress in agriculture, coupled with knowledge that N fertilizer prices probably will again greatly increase at some time in the near future, has resulted in many farmers again considering the use of legumes in their enterprises.

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Benefits from legumes

The ability of legumes to fix atmospheric N_2 and thereby add external N to the crop-soil ecosystem is a distinct benefit of legume culture. When fertilizer-N is expensive or unavailable, crop production systems depend on the N fixed by legumes to maintain the N cycle at a sustained productive level. Such limitations of fertilizer-N availability and cost are not uncommon in many developing countries.

The quantity of N biologically fixed each year by legumes varies greatly from zero to several hundred kg N per ha (Table 1). Many grain legumes are efficient at N fixation. Variables affecting quantity of N fixed include not only legume species and cultivar, but also such factors as soil type and texture, pH, soil nitrate-N level, temperature and water regimes, availability of other nutrients, and crop (especially harvest) management. The latter factor is extremely important. For instance, alfalfa *(Medicago sativa)* may add up to several hundred kg N/ha to the soil if a final cutting of hay is not removed, compared to less than 150 kg N if only the roots and stubble remain (Heichel, 1987).

The economic value of the N fixed by legumes also varies widely. One must consider the cost of production of the legumes, the amount of fixed N returned to the soil, and the availability of this N for future crops. Often, these costs are compared directly against the cost of purchasing and applying an equivalent amount of N fertilizer plus the net income lost by producing a legume instead of a grain crop (if the legume is grown in rotation). In the past several decades, the cost of production and price of N fertilizers have been such that this type of calculation would generally favor the use of N fertilizer. This fact is largely

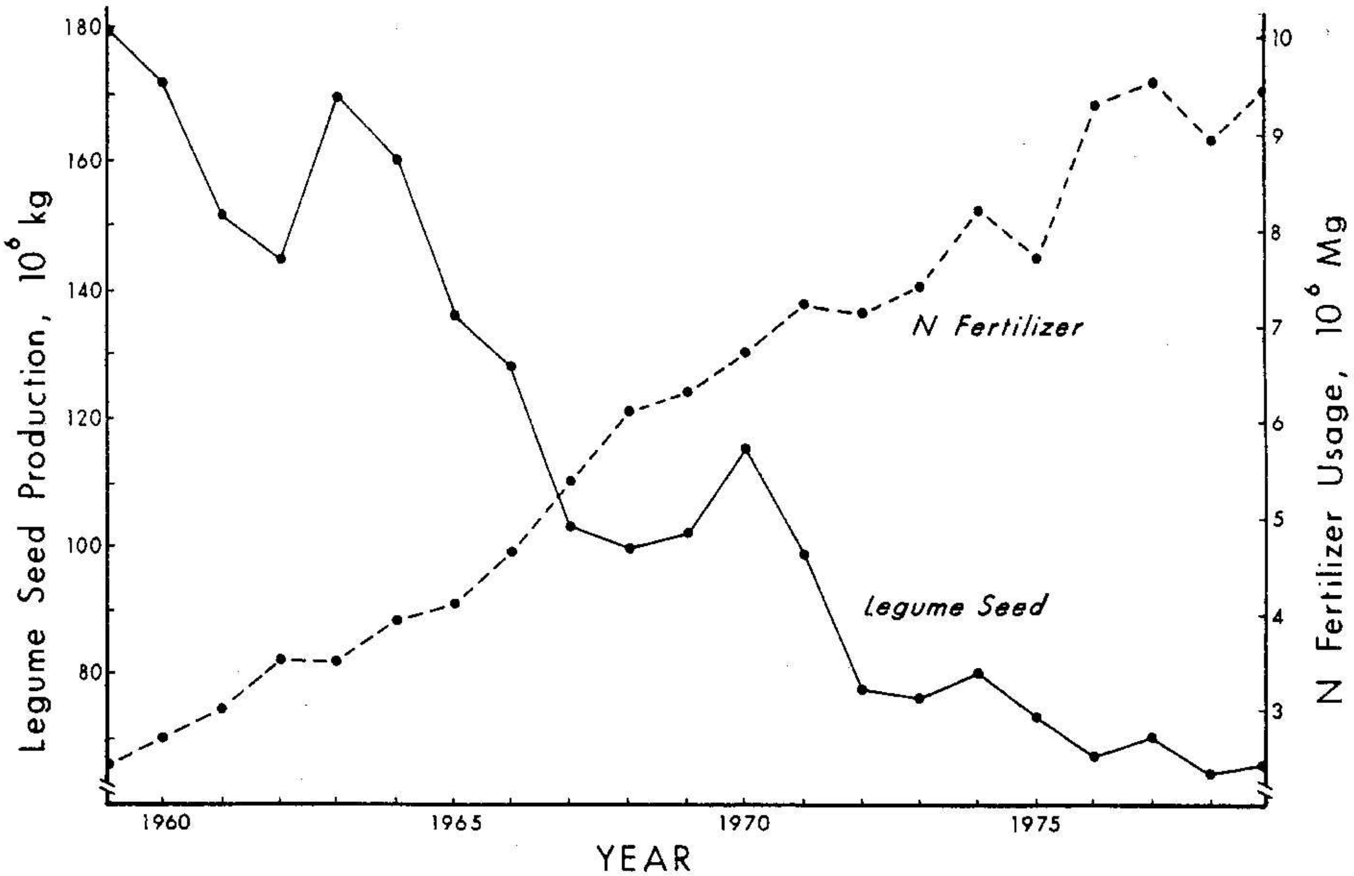

Figure 1. Changes in United States forage legume seed production and N fertilizer usage, 1959-1979 (Power and Papendick, 1985).

responsible for the decreased use of legumes in our crop production systems these past 40 years.

There are other benefits from using a legume on a cropping system that should be figured into any comparison with fertilizer-N, but unfortunately, they are often omitted because of difficulty in quantifying them. Usually, yields of a grain crop grown in rotation are at least 10 to 20 percent greater than those for continuous grain, regardless of the amount of fertilizer applied to the continuous grain (Table 2). This response is often referred to as the rotation effect. Because additional N will not entirely eliminate this yield difference, much of the response must be due to factors other than N availability. Cook (1984) and others have shown that rotation of crops reduces population and activity of some pathogenic soil organisms. Likewise, rotations break the weed and insect cycles that often predominate with continuous cropping. In addition, there is the possibility (although often difficult to prove) that rotations may enhance soil structure and improve air-water relations in the soil.

Legumes may have long-term benefits on some soils that again are difficult to convert into monetary value. Usually legume rotations, compared to continuous grain cropping, result in enhanced soil organic matter content and mineralizable N. This provides not only better control of N availability, but also improved soil structure, less energy for cultivation, and less erosion (Hoyt and Hargrove, 1986). Reduction in erosion rate, over a period of decades, can have a major influence on the properties and productivity of some soils (Mielke and

Table 1. Reported quantities of dinitrogen fixed by various legume species (adapted from Heichel, 1987).

Species	N fixed	Species	N fixed
	kg/ha/yr		kg/ha/yr
Alfalfa	114-223	Hairy vetch	111
Alfalfa-orchardgrass	15-136	Ladino clover	164-188
Clarke clover	21	Lentil	167-189
Birdsfoot trefoil	49-112	Red clover	68-113
Chickpea	24-84	Soybean	22-310
Common bean	2-121	Sub clover	58-183
Crimson clover	64	Sweet clover	5
Faba bean	178-251	White clover	128
Field peas	174-196		

Table 2. Effect of previous crop on corn grain yield (Langer and Randall, 1981).

Nitrogen rate	Previous Crop			
	Corn	Soybean	Wheat	Wheat-Alfalfa
kg/ha		Mg/ha[1]		
0	4.45	6.89	6.85	7.25
45	5.80	8.14	8.00	8.00
90	6.46	8.70	8.78	8.80
135	6.85	8.97	8.78	9.05
180	7.36	9.37	8.98	9.24
225	7.53	9.37	9.20	9.11

[1] Mg = megagrams = 10^6 gm = metric tons.

Schepers, 1986). The enhanced mineralizable N levels in soils with legume rotations compared to those for continuously cropped soils may aid greatly in control of ground water quality. With legumes, not only is less fertilizer-N required, but the level of nitrate N in the soil at any one time is usually less, so there are fewer nitrates to leach below the root zone.

Disadvantages of legumes

The obvious immediate monetary disadvantages of using legumes in cropping systems have been pointed out previously, using past prices for fertilizers and grain. Prices of grain have decreased greatly in recent years. Cost of fertilizer N will eventually increase because it is derived from a finite resource (natural gas), whose cost will increase as reserves are depleted. Thus, the direct monetary advantages of fertilizer-N over biologically fixed N that have predominated in the past may not be so great now or in the future.

When legumes are grown as rotation crops, they reduce total grain production per farm (or other unit of area) when compared to continuous cropping. If practiced on a national scale, total grain production for the nation would be decreased. Whether or not this change would be an advantage or a disadvantage to American agriculture is debatable, and is dependent upon changes in international markets, government policies, and other factors. If use of legume-based rotations were widely utilized, however, it is likely there would be an attendant increase in livestock production. Such a change again, on a national scale, would greatly change the livestock marketing picture and could be considered either an advantage or a disadvantage.

Because of the great decrease in legume production these past several decades, few legume seed producers remain and the cost of seed for many legume cultivars is relatively high, or large quantities of seed are not available at any price. Supposedly if there were greater demand for legume seed, more seed producers would go into business, and normal supply-demand relationships would be established.

Production of grain legumes, such as soybean, may result in greater erodibility of soil than occurs after a grain crop. Although this is a common observation, measurements of soil physical properties after soybean as compared to corn have generally failed to identify any one factor as being responsible (Fahad et al., 1982). Amount of soil erosion that actually occurs, of course, depends on the management practices used. For example, soil erosion on soybean land can be minimized by using no-till or reduced tillage techniques.

Pests are sometimes enhanced by including certain legume cultivars in a cropping sequence (Egunjobi, 1984). For instance, nematode problems in a corn-soybean rotation may be greater with than without using hairy vetch *(Vicia villosa)* as a winter cover crop. A few other examples of legumes intensifying pest problems occur under certain conditions. One of the most common is more difficulty in controlling some weeds when legumes are grown because of limitations on the kinds of herbicides that can be used. However, this disadvantage is often offset by breaking up weed growth cycles by the inclusion of a legume.

In rainfed agriculture, a major objection to including legumes in cropping systems is the competition for water that may exist between the legume and the subsequent grain crops. This competition is especially significant in semi-arid regions. Haas and Evans (1957) showed from over 40 years of dryland data at a number of Great Plains locations, that rotations that included alfalfa or sweetclover *(Melilotus)* usually produced lower wheat yields than those without legumes, even though legumes often increased soil organic-N content. This decrease was attributed to deeper and more thorough drying of the soil by the perennial legumes. Even after a year of fallow, soils plowed out of legumes generally contained 5 to 20 cm less soil water and yielded correspondingly less wheat. Under these limited water conditions, by growing a legume, enhanced N availability is traded for reduced water availability. In the wheat fallow regions of the Great Plains, water is often more deficient than N, so the N added by perennial legumes is of little benefit to the wheat.

Legumes used in rotation

Legumes are often used in rotation with cash grain crops. For purposes of discussion, we can divide this into long-term and short-term rotations. Long-term rotations would be those cropping systems in which the legume is the principal crop for more than one entire growing season, whereas in short-term rotations the legume is the primary crop for no longer than one growing season. An example of a long-term rotation would be alfalfa or clover grown in rotation with corn. The corn-soybean rotation would represent a common short-term rotation. Another short-term rotation might be continuous corn with a legume winter cover crop, such as hairy vetch.

The value of legumes in long-term rotation has been documented frequently in rotation experiments which were prevalent until the last few decades. Rothamstead in Great Britain, Morrow Plots in Illinois, and the Sanborn Fields in Missouri -- where classic experiments have been in progress for 100 or more years-- show the value of crop rotations which include perennial legumes. These experiments show that grain yields can be maintained at relatively high levels through the continued use of legumes in a rotation.

The effects of legumes on N availability and yield of following grain crops in a rotation are often significant for only one or two crops (Table 3). From 135 to 200 kg fertilizer N per ha had to be applied to continuous corn to achieve yield levels comparable to those obtained two to three years after a legume (Table 3). Total grain production over the period of the rotation is of course considerably less than for grain monocultures. In order to obtain maximum economic benefit from a rotation, many farmers incorporate a grazing livestock enterprise with the grain production enterprise -- seldom is a long-term legume rotation without livestock profitable.

Corn-soybean rotations are very common and are an example of a short-term rotation. Often corn yields after soybeans are greater than for continuous corn (Table 2), and often with less input of fertilizer-N. Part of this enhanced corn yield may result from greater N availability in soybean stubble compared to corn stover (Power et al., 1986). However, soybeans often result in a net N deficit in the soil because more N is removed in the harvested grain than is biologically fixed (Heichel, 1987). Thus, it is apparent that all the extra yield for corn following soybeans compared to continuous corn cannot be attributed to biologically fixed N. Undoubtedly the "rotation effect" is also a factor, breaking up weed, disease, and insect cycles, or providing undetermined benefits from residues or changes in physical properties.

A still shorter-term legume rotation is involved when cover crops are used. A common system, especially in southeastern United States, involves the use of a legume as a winter cover crop for continuous corn (Hargrove et al., 1985). Hairy vetch is commonly used for winter cover, although a number of other legumes could be planted. Hargrove (1986) found that these legume cover crops increased soil organic and inorganic N levels as well as yield of the following sorghum crop (Table 4). Sorghum yield increases from the legume cover crops were equivalent to responses to application of 61 to 97 kg fertilizer N per ha. There are also other benefits from the winter cover crop--soil erosion control (especially after silage corn), reduced runoff, and reduced leaching of nitrates (and better ground water quality).

Table 3. Corn grain yields as affected by number of years after a legume in a rotation (Voss and Shrader, 1984).

Soil Association	Years since legume			Continuous corn	
	1	2	3	N applied	Yield
	Mg/ha[1]			kg/ha	Mg/ha
Clarion-Webster	8.16	7.91	7.66	200	7.41
Grundy-Shelby	7.47	7.09	—	200	7.22
Galva-Primghar	8.10	7.97	—	135	7.22
Carrington-Clyde	7.28	6.59	—	180	6.65
Lancaster	8.22	7.72	7.53	168	7.28

[1] Mg = megagrams = 10^6 gm = metric tons.

Summary

With the development of new technologies in the last few decades and the prospect for even greater developments in the future, agricultural scientists need to rethink the potential role of legumes in soil and crop management systems. Earlier generations used legumes because they provided a dependable source of added N as well as a forage base for the livestock systems which were almost mandatory for most farmers. The introduction of inexpensive N fertilizers, herbicides, and other pesticides, improved cultivars, mechanical power and better designed machinery, and other advancements made it possible and economically profitable for many farmers to convert from legume-based crop rotations to monocultures or simple rotations of grain crops. However, the energy crisis of the late 1970's showed that this production system was highly vulnerable to the volatile supply and demand price structure of foreign oil. Monocultures also often increased soil erosion potential, increased risk, required more capital, and had other limitations (Power and Follett, 1987).

The primary question today is how to produce crops in a manner that is economically profitable, environmentally acceptable, and sustainable. Because legumes offer an alternative sources of N, usually aid in soil erosion control, and offer potential for improvement of surface and ground water quality, we need to know how we can most effectively utilize legumes in cropping systems. In only limited situations is it probable that the legume-based crop rotations of earlier generations will be useful because farmers no longer need to produce feed for draft animals, because cattle production and feeding is frequently no longer integrated with crop production enterprises, and because the availability of fertilizer-N and improved tillage practices for erosion control reduce need for rotations. However, there are a number of opportunities for using legumes in

Table 4. Soil inorganic and organic N in the 0 to 75 mm depth and sorghum grain yields following winter cover crops (Hargrove, 1986).

Cover Crop	Soil N		Sorghum yield	
	Inorganic	Organic	0-N	112-N
	kg/ha	g/kg	Mg/ha[1]	
Fallow	8	0.58	2.89	3.91
Rye	8	0.65	2.56	3.87
Crimson clover	14	0.65	3.91	4.22
Subterranean clover	20	0.81	3.88	3.86
Hairy vetch	21	0.80	3.96	3.79
Common vetch	14	0.63	3.66	3.95

[1] Mg = megagrams = 10^6 gm = metric tons.

short-term situations—such as simple rotation, double cropping or intercropping, and as cover crops. We need to know the ability of various legume species and cultivars to grow and to fix atmospheric N, as well as amount and depth to which soil water is depleted. We need this information for various seeding dates and temperature regimes. With this type of information, we can then select the best legume cultivars to use for a particular situation, whether it be to intercrop with small grain, short-term rotation (such as double cropping), use as a winter cover crop, or for other uses. We need much research to obtain some of this basic information so that we can design the ideal cropping and management systems for a given climate.

Acknowledgment. This paper is a contribution from the Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the Nebraska Agricultural Research Division, University of Nebraska, and is published as Journal Series Number 8272.

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